Should You Swipe Right? Two-Sided Search in Swipe-Based Dating Applications

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Abstract

In today's love market, swipe-based dating apps such as Tinder or Bumble have a well-established presence, but novel platform features can add significant complexities to the user's search problem in ways that have gone largely under-studied in existing literature. This paper formulates a game-theoretic model of two-sided search within swipe-based dating apps, along with an appropriate equilibrium refinement. Using numerical methods, I approximate equilibria at the steady-state and perform comparative statics on various model parameters that help explain stylized facts observed in aggregate Tinder data. Finally, agent-based simulations are used to analyse off-path dynamics and discuss how exogenous platform features can be set in a socially-efficient manner.

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1 Introduction

It is widely acknowledged that the search for love is a complex social phenomenon, but in today's world, swipe-based dating applications (SBDA's) seem to only make it trickier. These platforms, exemplified by Tinder, Bumble, or Hinge, provide a gamified way of browsing through potential romantic partners by swiping through a stack of suggested candidates to indicate likes or dislikes for these, one profile at a time. In the search and matching literature, settings like these fall under the category of decentralized two-sided matching markets with online search (Kanoria and Saban, 2021), emphasising three main characteristics. Firstly, that both sides of the market are comprised of decision-making agents undertaking a process of search. Secondly, that matches occur as outcomes of independently-determined search decisions, rather than through a centralised algorithm. Thirdly, that romantic suggestions are presented in an online manner to users, stressing the importance of sequential rationality given that it is not possible to revert interactions with previous candidates. These apps differ widely from traditional dating sites where users are centrally and statically matched (such as match.com or eHarmony), but have come to dominate the modern love market, with Tinder alone boasting 75 million monthly active users and 9.6 million paid subscribers as of 2021 (Business of Apps, 2022).

From a theoretical standpoint, search within SBDA's induces several additional complexities due to platform-specific features, such as swiping caps, asynchronicity, and directed search algorithms. These impose non-trivial constraints on the way utility-maximising agents strategise their search process, but they have been sparsely studied in the economics literature due to the relative novelty of these platforms. Overall, the prevalent role of SBDA's in shaping modern romantic interactions and their largely understudied nature motivates many different questions. Nevertheless, exploring these demands a fundamental understanding of how users make decisions in these platforms: to put it simply, *when should a utility-maximising user swipe right?*

This dissertation will explore the above within an SBDA platform setting, where agents with heterogeneous preferences on both sides of the market search simultaneously for multiple romantic partners. Crucially, I focus on explaining (what I refer to as) the 'Fast-Swiping Males' puzzle: that is, the empirical observation that men in SBDA's respond with significantly higher swipe rates and face considerably worse matching outcomes than women. This phenomenon has been both a subject of empirical research (Tyson et al., 2016) and an extensively documented discussion point within mainstream media (Vice News, 2016; The Washington Post, 2016) and yet, in spite of this, a significant gap persists within the literature for a discussion of this through a theoretical lens [1]. This analysis is of vital importance given that the multiple factors that often get blamed for this phenomenon (user patience, differential preferences, and strategic dominance) are all systematically endogenous with one another, thus demanding a rigorous model that can isolate these individual effects and capture their propagation across the SBDA market. Fundamentally, I argue that gender imbalances within the platform (which arise due to several exogenous factors) can explain swipe rate disparities within the platform and, expanding on this, I model a possible intervention where the swiping cap ratio between sexes can be set in a socially-efficient manner.

This work presents two main contributions to existing literature on the topic. Firstly, it constitutes one of a handful of attempts to model the market configurations arising

[1] Among the surveyed literature, perhaps the only partial examination of this phenomenon is provided by Kanoria and Saban (2021)

within SBDA's, which is unsurprising due to the novelty of these platforms, but important given their current social relevance. Furthermore, this work distinguishes itself by considering the impact of swiping caps in the market, both as a constraint within the agent's search problem and a potential market correction mechanism. Finally, this work provides an interesting case study for the use of computational methods within game theory, a field that has traditionally emphasised pure mathematical analysis. By pairing a rigorously-formulated model with numerical approximations and agent-based simulations, this dissertation exemplifies how the two approaches, rather than being mutually exclusive, can be jointly employed to explore complicated questions, as computational methods enable quick explorations that can serve as a stepping stone towards formalising mathematical arguments.

The remainder of the paper is structured as follows. In Section 2, I outline the theoretical framework for the model developed in this paper, and derive necessary conditions for both the system steady state and the agent best-response correspondences. In Section 3, I present a refined definition for the steady state equilibrium of the model and perform computational comparative statics on several parameters, with the aim of replicating stylized empirical facts and explaining the 'Fast-Swiping Males' phenomenon. In Section 4, I utilize agent-based simulation methods to analyse convergence and dynamics of my model, and present a discussion on socially-efficient budget interventions. Finally, Section 5 presents concluding remarks and outlines potential avenues for future research.

1.1 Related Work

The present work draws inspiration from two key branches of economics literature: that of search and matching, which studies the decision-making process of agents who seek, for example, a job, a business partner, or a spouse, and that of mean field game theory, which models complex dynamic games involving a large number of players. I discuss each of these in turn, and then contrast this work with the handful of papers that have focused on specifically analysing SBDA market configurations.

Despite the abundance of papers within the search and matching literature, which has been amply surveyed by Chade et al. (2017), I draw focus on works that consider the three defining features of SBDA markets: decentralised matching, two-sidedness, and bilateral sequential interactions. A seminal paper at the heart of this intersection is that of Burdett and Coles (1997), which studies the marriage market for ex-ante heterogeneous agents under uniform random search, extending the work of Becker (1973) by showing that positive assortative matching can arise even in the absence of log-supermodularity. Several extensions followed this work, considering settings with idiosyncratic preferences (Burdett and Wright, 1998), noisy attractiveness observations (Chade, 2006), and even convergence onto the set of stable matchings (Adachi, 2003). These various different 'flavours' of two-sided matching models served as great inspiration for this dissertation, and the framework developed hereafter is perhaps most similar to that of Burdett and Wright (1998), with three major distinctions. Firstly, the model formulated in this paper extends the above by allowing for multiple partners within a user's lifetime, a feature which was probably not significant within the labour market context considered by Burdett and Wright (1998), but which proves quintessential given the role of SBDA's in enabling casual relationships. Furthermore, the model I present extends the above by allowing for sex-specific mass differences, as well as exogenous agent inflows; a point which was noted as a worthwhile extension by Burdett and Wright themselves, and which is fundamental in order to consider the effects of gender imbalances within the platform. Finally, the framework developed in this paper considers a discrete time framework, unlike Burdett and Wright (1998) and most other works in the matching literature. Although continuous-time models provide sharper analysis and more flexible empirical specifications (Burdett and Coles, 1999), this modelling choice lends itself naturally to the use of agent-based simulations, which are employed to asses convergence and model dynamics in a richer manner.

On the other hand, mean field game theory focuses on dynamic games with a large number of agents, for which curses of dimensionality often arise due to intractable state spaces (Maskin and Tirole, 2001). To deal with this, mean field models consider individual interactions with the *aggregate state* only, ie. the distributions over states and strategies within the game, rather than interactions with all other players. This abstraction is coupled with the notion of a *consistency check*, such that equilibrium arises when rational play given an aggregate state maintains this same state as a fixed point. The approach, first considered in the work of Jovanovic and Rosenthal (1988), greatly simplifies strategic settings with the aforementioned problem and has been successfully applied to settings such as network routing (Calderone and Sastry, 2017) and dynamic auctions with learning (Iyer et al., 2014). In this paper, we rely on mean-field assumptions to abstract from observability considerations: within SBDA's, the market-wide history is unobservable to players, and thus traditional equilibrium concepts would demand beliefs over uncountable history spaces, and even beliefs over the beliefs other players may hold (a complication known as nested beliefs (Brandenburger and Dekel, 1993)). This yields two central problems: first, that equilibria become virtually impossible to compute, and, by extension, that the model assumes an unreasonable level of rationality on behalf of agents. Thus, by considering interactions with the platform state, the model presented in this paper characterizes equilibria that are both insightful and representative of real-life behaviour and dynamics.

Among the few papers that specifically consider SBDA matching markets, one that stands out is the recent work by Kanoria and Saban (2021), which postulates a two-sided dynamic matching model with vertically-differentiated agents, and finds that platforms with unbalanced markets can improve welfare by forcing the short side to propose. Furthermore, the work presented by Immorlica et al. (2021) focuses on the problem of determining a directed search algorithm in SBDA's through type-contingent meeting rates for agents. Both of these papers contain similar features within the theoretical models they develop, and these have largely influenced my work in several ways; for example, by embedding mean-field assumptions that simplify the SBDA market from a game theoretical perspective. Despite this, there are three main differences between my work and above that are worth discussing.

2 Theoretical Model

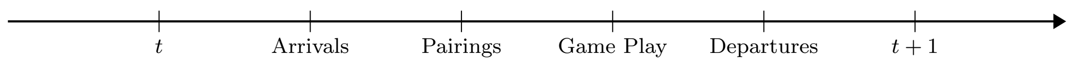
2.1 Setup

Throughout this section, I establish the theoretical framework for the model considered in this paper. Fix a non-atomic continuum of male and female agents and consider the dynamic two-sided market formed by the SBDA platform, which agents can join to search for potential romantic partners. For ease of exposition, I assume that this market is heteronormative such that male agents search exclusively for female agents and vice-versa. Time is discrete and indexed $t = 0, 1, 2, ...$ over an infinite horizon. At every time period, agents from each sex are paired and presented a candidate partner from the opposite side of the market. We model agents with heterogeneous preferences (capturing the notion that 'beauty lies in the eye of the beholder') and thus, after being paired, each agent observes an *idiosyncratic attractiveness value* $\theta \in \Theta := [0, 1]$ for their candidate. These values are drawn i.i.d from distributions with CDF's F_m, F_w, with female agents drawing male candidate values from F_m and vice versa. Importantly, the value men i draws for women j does not necessarily equal the value that j draws for i, and, for simplicity, these are modelled these as independent from one another.

After observing their candidate's attractiveness, agents then choose whether to swipe left (dislike) or right (like) on them, yielding an action space of $\mathcal{A} = \{\text{left}, \text{ right}\}$. If both agents swipe right on one another, they are said to have *matched* and both receive a matching payoff, however, if either agent swipes left, they both receive a payoff of zero. Contingent on swiping right on a candidate with attractiveness θ, a user earns a matching payoff $u(\theta)$, where $u(\cdot)$ is a continuous, strictly increasing function that satisfies $u(0) = 0$. This last property stems from the fact that, in Tinder, users are allowed to unmatch with each other, thus implying that matching with the least attractive individual on the other side of the market is weakly preferred to not matching.

After payoffs have been received, players are paired to different candidates and the stage interaction is repeated. Given the continuum of agents, I assume that interactions take place *anonymously* in the style of Jovanovic and Rosenthal (1988). Furthermore, to the agents' knowledge, pairings are determined in an unknown manner (since SBDA's are generally secretive regarding the algorithms used), effectively making their problem one of uniform random search.

Figure 1: Sequence of events within each time period



Perhaps trivially, swiping right in the stage interaction described above is both weakly dominant for all agents and yields a Pareto-optimal outcome, thus implying that, in a repeated interaction, the market equilibrium would have all agents exclusively swiping right. Despite this, the main selling point of SBDA's is a reduction in searching costs for individuals seeking romantic encounters, and this is only accomplished if matches have a high likelihood of resulting in real-life romantic attraction. Because of this, SBDA's like Tinder place a cap on the total number of right swipes for each user, thus enabling this as a form of costly signalling. I refer to the total number of right-swipes a user has left as its *budget*, b_t, which evolves dynamically according to the law of motion:

$$b_{t+1} = b_t - a_t$$

where the budget caps for each sex, B_m and B_w, are determined exogenously. The budget sets for men and women are thus defined by $\mathcal{B}_s = \{b \in \mathbb{Z} : 1 \leq b \leq B_s\}$, for each sex $s = m, w$. Each period, new men and women enter the platform at rates $\lambda_m, \lambda_w > 0$. Importantly, agents depart from the platform in one of two ways: they can leave *endogenously*, if they expend their swiping budget, or *exogenously* with probability $(1 - \delta)$. This admits to the interpretation of a geometrically distributed lifetime within the platform, parametrised by δ, and implies that users use this as a discounting factor for future payments.

Due to the anonymity assumption above, agents can relax history-related considerations, essentially simplifying their stage problem to one that depends on the candidate attractiveness and their own budget only. Due to this, I restrict focus to stationary Markovian strategies, denoted by $\mu : \Theta \times \mathcal{B}_m \to \Delta\mathcal{A}_m$ for men and $\omega : \Theta \times \mathcal{B}_w \to \Delta\mathcal{A}_w$ for women, where ΔS denotes the probability simplex over set S.

2.2 The Dating Market

Given the sequence of events taking place in the stage interaction, I now outline the system state variables that make up the Tinder market. Let $N_{mt}(b), N_{wt}(b)$ denote the mass of male and female agents (respectively) with a budget of $b \in \mathcal{B}$ in a given time period t. Furthermore, since gender imbalances can leave some agents in the long side of the market unpaired, a pairings process must be fixed. Given fairness considerations as well the automated nature of SBDA platforms, I assume an efficient matching technology and model pairings as a Bernoulli process parametrised by market tightness; thus, the probability of being paired with a candidate is defined for both sides as:

$$\tau_{mt} := \min\left\{\frac{N_{wt}}{N_{mt}}, 1\right\}, \quad \tau_{wt} := \left(\frac{N_{mt}}{N_{wt}}\right)\tau_{mt}$$

From the above, the platform state at time period t can be defined as $\Psi_t = (N_{mt}, N_{wt})$. For most of this paper, I focus on characterising user behaviour and its resulting implications in a stationary setting (which is denoted by omitted time subscripts), although some discussion of coupled strategy and market dynamics is provided in Section 4. As a necessary requirement, the market steady state $\Psi_t = \Psi_{t+1} = ... = \Psi$ must satisfy the balanced flow conditions [2] for our continuum model; these are presented below for the female agents, but they apply analogously to the male side of the market. Firstly, the entry flow of agents into the platform must equal the departure flow:

$$\lambda_w \;=\; \underbrace{(1-\delta)\sum_{b\in\mathcal{B}_w} N_w(b)}_{\text{Exogenous Outflow}} \;+\; \underbrace{N_w(1)\delta\tau_w \int_\Theta \omega(\theta, 1)\, dF_m(\theta)}_{\text{Endogenous Outflow}} \tag{2.1}$$

Secondly, for both sides, the flow of agents into any particular budget level must equal the outflow of agents from that same level. Thus, for all $b \in \mathcal{B}_w$:

$$\underbrace{N_w(b+1)\delta\tau_w \int_\Theta \omega(\theta, b+1)\, dF_m(\theta)}_{\text{Inflow into } b} \;=\; \underbrace{N_w(b)\Big[(1-\delta) \;+\; \delta\tau_w \int_\Theta \omega(\theta, b)\, dF_m(\theta)\Big]}_{\text{Outflow from } b} \tag{2.2}$$

Finally, the entry flow of agents into the platform must equal the outflow from the top budget level, hence:

$$\lambda_w \;=\; \underbrace{N_w(B_w)\Big[(1-\delta) \;+\; \tau_w\delta \int_\Theta \omega(\theta, B_w)\, dF_m(\theta)\Big]}_{\text{Outflow from } B_w} \tag{2.3}$$

[2] Formally, these conditions rely on the exact law of large numbers, which has been rigorously developed for discrete-time settings by Duffie et al. (2018), but a technical discussion of this lies outside the scope of this paper

2.3 The Search Problem

With the model framework and market dynamics outlined above, I now explore the decision problem faced by female agents in the market, with analogous results and implications for the male side. In the discussion below, I derive the female best-response function given a fixed, stationary market state Ψ and male strategy μ. To begin this analysis, consider a woman i who is paired with a man j in Tinder. The expected ex-interim payoff for this women, given that she observes attractiveness θ for candidate j and chooses action a, is the following:

$$U(\theta, a) = \Big(\overline{\mu}\, \mathbb{1}\{a = \text{right}\}\Big)\, u(\theta), \quad \text{where} \quad \overline{\mu} \;= \sum_{b \in \mathcal{B}_m} \int_{\Theta} \mu(\theta', b)\, N_m(b)\, dF_w(\theta')$$

Here, $\overline{\mu}$ denotes candidate j's strategy averaged over the possible attractiveness values that he may observe for i and his possible budget level, both of which are unknown to woman i. The payoff function above imposes a mean-field assumption where, conditional on the fixed platform state Psi, woman i averages out her opponent's strategy, rather than considering candidate j's specific behaviour and beliefs over his possible budget level. This modelling choice has been employed by Immorlica et al. (2021) and Iyer et al. (2014) among others, as it simplifies the full-fledged dynamic game by collapsing it onto a pair of Markov Decision Processes (MDP's), where strategy ω is a best response for female agents if and only if it is an optimal policy for the corresponding MDP. Consider the arrival times of the realized pairing process for woman i and index these by k. Given that, at the time of pairing, this women has a budget of b right swipes left, she then solves the constrained MDP presented below, captured by the value function $V_w(\theta, b)$:

$$\begin{aligned} V_w(\theta, b) = \max_{\{a_t\}_{t=0}^{\infty}} \quad & \mathbb{E}_\theta \left[\sum_{t=0}^{\infty} \delta^t U(\theta_t, a_t) \mid \theta_0 = \theta, b_0 = b \right] \\ \text{s.t.} \quad & b_{t+1} = b_t - a_t \\ & b_t \in \mathcal{B}_w \cup \{0\} \\ & a_t \in \mathcal{A} \end{aligned}$$

Importantly, the first two constraints along with the exogenous departure process make this problem non-trivial; by limiting woman i's right-swiping budget, the platform imposes an opportunity cost between swiping right on man j and foregoing potential future matches with more attractive men, whilst the exogenous departure process removes the possibility of simply waiting around to swipe right on the top B_w most attractive men. By standard dynamic programming arguments, this problem can be captured by two Bellman equations; one for when j is paired and another for when she isn't:

$$\begin{aligned} V_w^P(\theta, b) = \max \Big\{ & \overline{\mu}\, u(\theta) \;+\; \delta\tau_w\, \mathbb{E}_\theta\Big[V_w^P(\theta', b-1)\Big] \;+\; \delta(1-\tau)V_w^{NP}(b-1)\,, \\ & \delta\tau_w\, \mathbb{E}_\theta\Big[V_w^P(\theta', b)\Big] \;+\; \delta(1-\tau_w)V_w^{NP}(b) \Big\} \end{aligned} \tag{2.4}$$

$$V_w^{NP}(b) = \delta\tau_w\, \mathbb{E}_\theta\Big[V_w^P(\theta', b)\Big] \;+\; \delta(1-\tau_w)V_w^{NP}(b) \tag{2.5}$$

With some straightforward algebra, the above two equations can be merged into the full Bellman equation below. Note that, to impose the swiping budget constraint from the above MDP, it must be the case that $V(\theta, 0) = 0, \ \forall \theta \in \Theta$, since agents with no right-swipes left must leave the platform and can't accumulate any additional payoffs:

$$V_w(\theta, b) \ = \max \Big\{ \, \overline{\mu} \, u(\theta) + \alpha \, \mathbb{E}_\theta \Big[V_w(\theta', b-1) \Big] \, , \ \alpha \, \mathbb{E}_\theta \Big[V_w(\theta', b) \Big] \, \Big\} \tag{2.6}$$

Where α is the effective discount rate accounting for the exogenous possibilities of both departures and pairings, defined as:

$$\alpha := \frac{\tau_w \delta}{1 - \delta(1 - \tau_w)}$$

Upon inspection, it is clear that the value function is of a piecewise nature in θ; thus, the optimal policy can be determined by a set of reservation attractiveness levels, $\{\tilde{\omega}\}_{b \in \mathcal{B}_w}$, where women j swipes right for partners who exceed the reservation level for her current budget. These reservation levels must be such that woman i is indifferent between swiping left or right, thus:

$$\omega(\theta, b) = \begin{cases} 1, & \theta \geq \widetilde{\omega}_b \\ 0, & \theta < \widetilde{\omega}_b \end{cases} \quad , \quad \text{where } \widetilde{\omega}_b \text{ satisfies:}$$

$$\overline{\mu} u(\widetilde{\omega}_b) = \alpha \, \mathbb{E}_\theta \Big[\, V(\theta', b) - V(\theta', b-1) \, \Big]$$

Although reservation attractiveness levels can be computed using numerical algorithms such as value or policy iteration (Rust, 1987), they are more explicitly characterized by the result below (with a corresponding proof included in Appendix A):

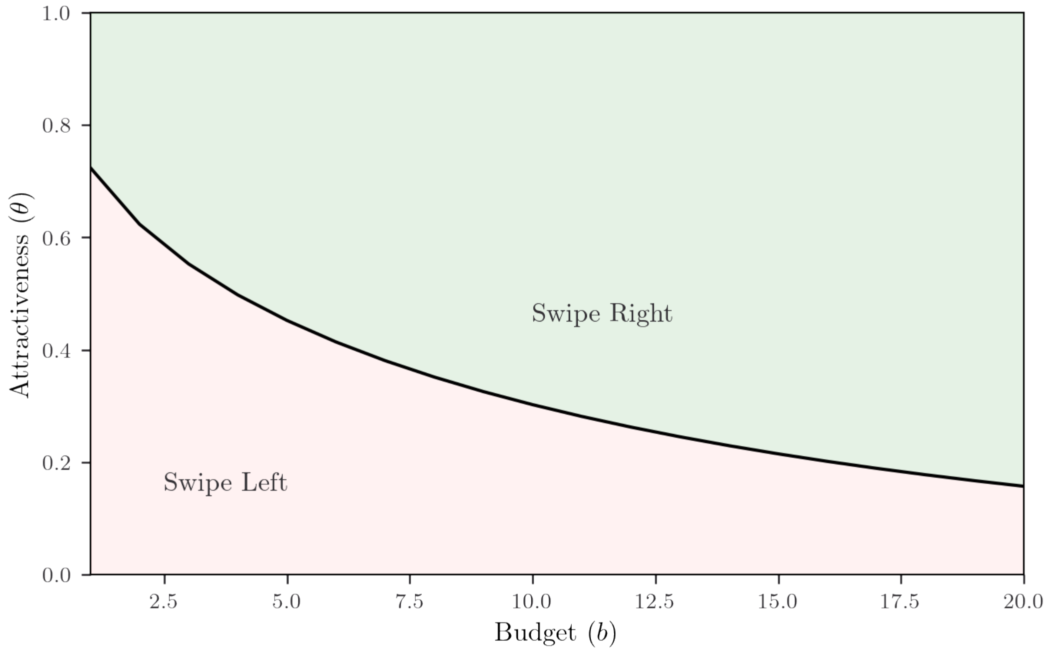
Proposition 1. *The set of reservation attractiveness levels for women, $\{\tilde{\omega}_b\}_{b \in \mathcal{B}_w}$, uniquely satisfies the recurrence relation and initial condition below, over the budget set $\mathcal{B}_w$:*

$$u(\widetilde{\omega}_b) \ = \ \alpha u(\widetilde{\omega}_b) F_m(\widetilde{\omega}_b) \ + \ \alpha u(\widetilde{\omega}_{b-1}) \Big[1 - F_m(\widetilde{\omega}_{b-1}) \Big] \ + \ \int_{\widetilde{\omega}_b}^{\widetilde{\omega}_{b-1}} \alpha u(\theta') \, dF_m(\theta') \tag{2.7}$$

$$u(\widetilde{\omega}_1) \ = \ \alpha u(\widetilde{\omega}_1) F(\widetilde{\omega}_1) \ + \ \alpha \int_{\widetilde{\omega}_1}^{1} u(\theta') dF(\theta') \tag{2.8}$$

By further inspecting this result, it is evident that the aggregate behaviour of the opposite side of the market ($\overline{\mu}$) has no direct influence over female best responses. Instead, this influence happens indirectly through the steady state masses and their effect on how agents discount inter-temporal payoffs through α. Using the recurrence relation in Proposition 1, the agent-best response was computed for an arbitrary set of exogenous parameters, with results shown in Figure 2. As evidenced by these, the optimal policy (and best-response function) for agents is marked by a clear cut-off rule for swiping right. These cut-off values are decreasing in the agent's budget, which captures the notion that an agent's current swipe is more valuable than all preceding ones given the increasing opportunity cost.

Figure 2: The Optimal Swiping Rule



3 Equilibrium & Comparative Statics

3.1 Steady State Equilibrium and Approximation

Using the framework and results above, I now present a refined definition for the steady state equilibrium of the market:

Definition 1. *A Steady State Equilibrium is defined by a triplet* $(\mu^*, \omega^*, \Psi^*)$ *such that:*

1. $\mu^*(\theta, b)$ *attains* $V_m(\theta, b)$, $\forall\, \theta, b \in \Theta \times \mathcal{B}_m$, *given* ω^*, Ψ^*
2. $\omega^*(\theta, b)$ *attains* $V_w(\theta, b)$, $\forall\, \theta, b \in \Theta \times \mathcal{B}_w$, *given* μ^*, Ψ^*
3. Ψ^* *satisfies Equations 2.1, 2.2, and 2.3 given the strategy profile* (μ^*, ω^*)

Intuitively, the above definition establishes two conditions that must be satisfied by an equilibrium market configuration. Firstly, it must be the case that μ^* and ω^* are mutual best responses given the platform state Ψ^*; however, as previously outlined, a necessary and sufficient condition for this would have them each solve the sex-specific MDP. This essentially rules out mixed-strategy equilibria which would never be optimal for either MDP. Furthermore, in line with mean-field game theory literature, a *consistency check* is imposed by the third condition, which requires that the platform steady-state to which agents are best-responding with (μ^*, ω^*) is sustained. Overall, the above equilibrium concept demands *partially rational expectations* from agents, as ....

Although formal proofs of existence and uniqueness for steady-state equilibria are outside the scope of this paper, I instead rely on computational procedures[3] to approximate equilibria under various exogenous configurations to shed some light on the insights

[3]The code required to reproduce all analysis presented in this paper is fully accessible under the GitHub repository `patohdzs/project-tinder`

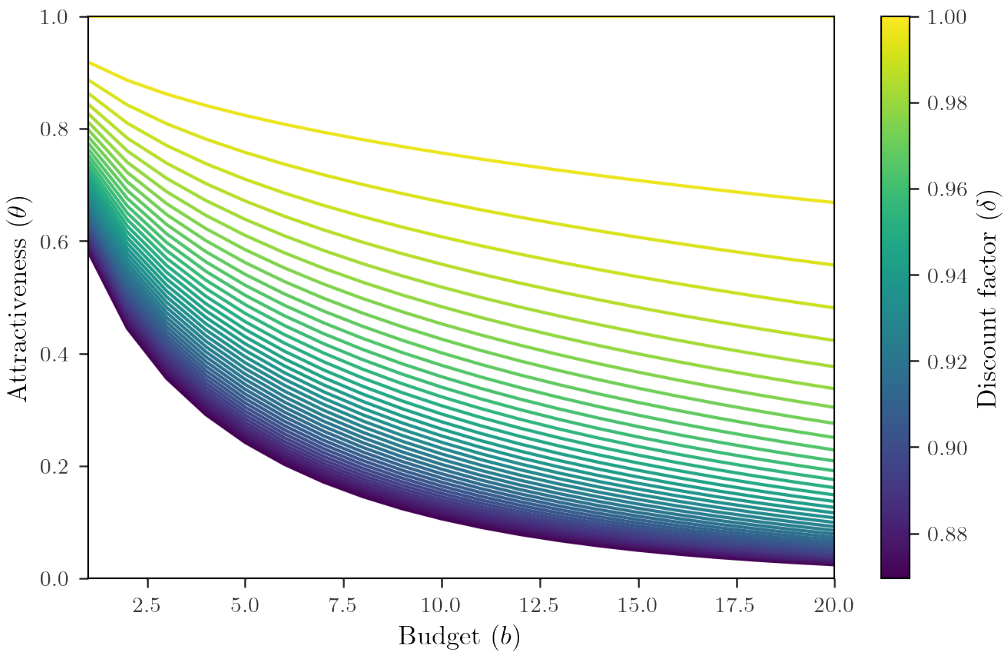
provided by the theoretical model and its ability to replicate and explain stylized empirical facts. I propose two computational procedures to solve for model equilibria, both of which involve framing the recurrence relation presented in Proposition 1, as well as Equations 2.1, 2.2, and 2.3, as a system of $2(|\mathcal{B}_m| + |\mathcal{B}_w| + 1)$ non-linear equations, denoted by $\mathbf{E}(\mu, \omega, \Psi)$. From here, the first procedure utilizes a modified version of Powell's method, as per the MINPACK 1 routine (Moré et al., 1980), whilst the second one solves the following least squares problem:

$$\mu^*, \omega^*, \Psi^* = \arg\min_{\mu,\omega,\Psi} \quad ||\mathbf{E}(\mu, \omega, \Psi)||^2 \quad \text{s.t.} \quad \mu, \omega \in [0, 1]$$

3.2 Best Response Analysis

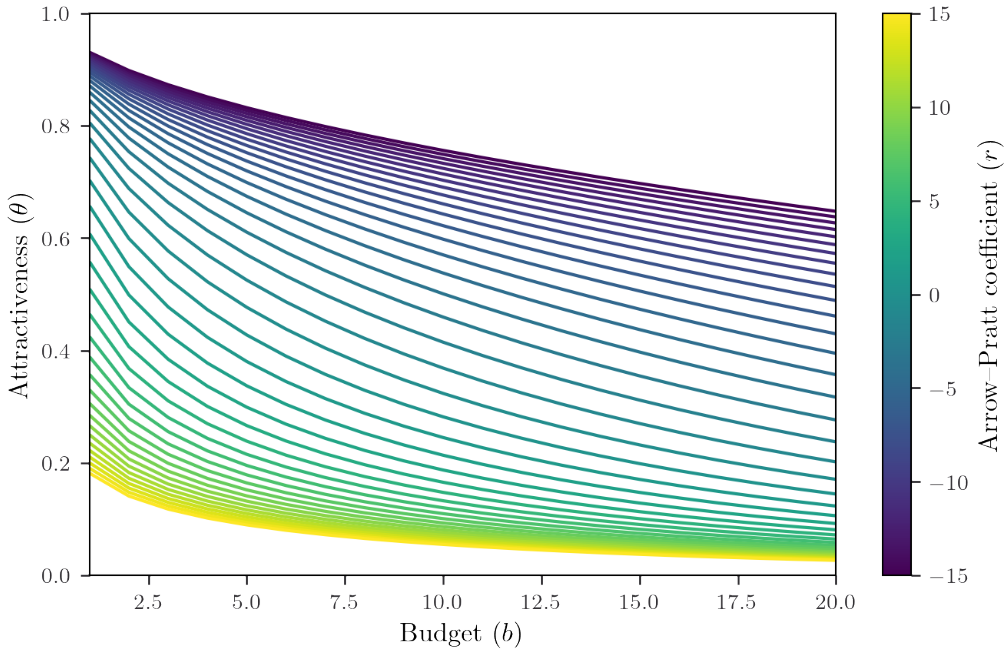
Using the computational procedures outlined above, a number of insights can be uncovered related to how exogenous parameters affect an agent's best-response swiping strategy. The first parameter I analyse is the discount factor, which represents the probability of remaining inside the platform for an additional time period, but is often interpreted as the representative agent's patience level. To determine the effects that changes in the discount factor have on the best-response policy, I computed the latter over a range of different values for δ (using an arbitrary set of exogenous parameters), with results shown in Figure 3. Evidently, as the agent becomes less patient, they 'lower their standards' for potential matches in the platform, shifting their swiping curve downwards.

Figure 3: Comparative Statics on the Discount Factor



Another interesting parameter to examine is the absolute risk aversion of agents, which I choose to interpret as their 'desperateness' for matching in the platform. In the platform, risk-averse agents prefer a higher chance of matching (even if these matches yield relatively lower payoffs), whilst risk-loving agents prefer to wait around and save their swipes for high-yield candidates. To perform comparative statics on this parameter, I fix a CARA utility function for agents, with parameter r denoting the Arrow-Pratt coefficient for absolute risk aversion. With these preferences, I then compute the optimal swiping rule for various different values of r and an arbitrary set of exogenous parameters, with results for this shown on Figure 4. From this, it is evident that as agents become 'more desperate' for matches, implied by rising absolute risk aversion, they lower their standards for right-swiping on a candidate, thus shifting their swiping curve downwards (as one would intuitively expect).

Figure 4: Comparative Statics on Absolute Risk Aversion

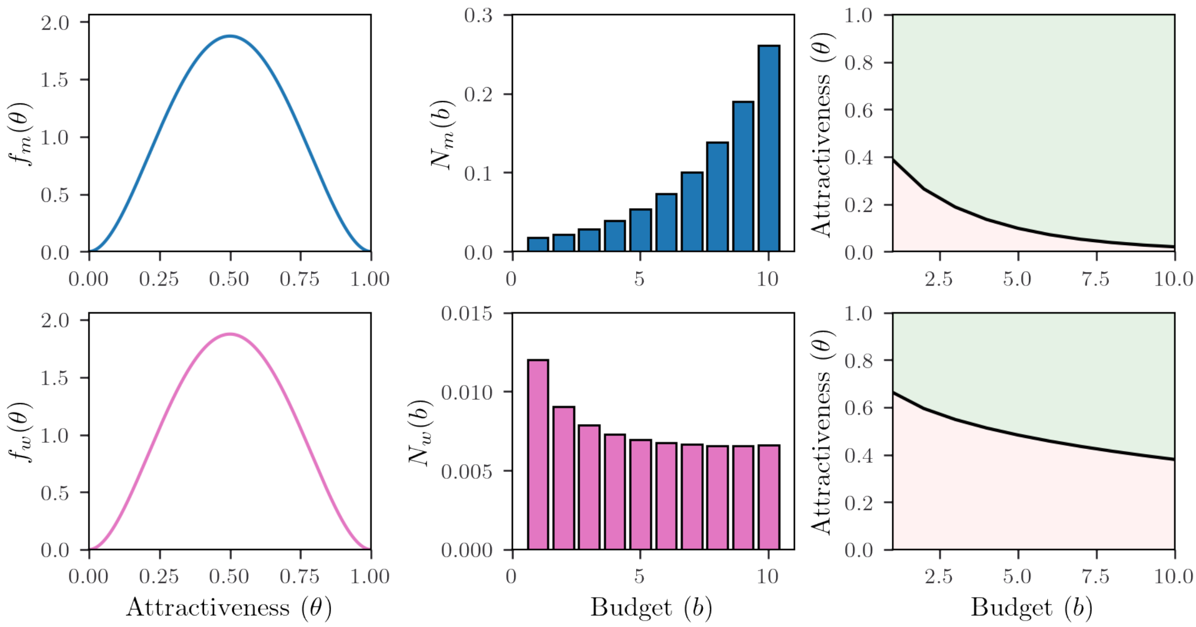


3.3 Market Configuration Analysis

Finally, I perform comparative statics at the platform level to determine how different factors affect market configurations. This is especially important as it considers not only the effects on best-responses for one sex, but also how these affect the market as a whole through the aggregate state. More specifically, I focus the aforementioned 'Fast-Swiping Males' puzzle,investigating the discrepancy in swiping rates and matching outcomes between men and women, and I present three possible explanations for how the model developed in this paper can replicate and explain this outcome. The first explanation concerns differential inflows for both men and women, which occur exogenously within my model but are in line with empirical findings, which . To asses the market configurations arising from of this situation, I compute the model equilibria under a 6:1 ratio between arrival rates λ_m and λ_w. The results for this are shown in Figure 5, highlighting three main insights for this scenario.

Firstly, under differential agent inflows, the mass of male agents in the platform is around ten times greater than that of female agents, implying that male agents face a tight market and struggle to get paired with female candidates. This is further evidenced by the top-center plot within Figure 5, which shows that male agents are highly concentrated in the top budget levels. Due to the effect of market tightness on the effective discount

Figure 5: Market Configuration Under Differential Agent Inflows



rate, male agents are also more impatient than women on the platform, which makes sense intuitively as they also face considerably worse matching odds. This effect is captured by their best-response strategy, which sits considerably lower than the female swiping curve, effectively showing how a congested market lowers male patience and by extension, their standards, leading them to swipe right on most women. Ultimately, this explains the 'Fast-Swiping Males' puzzle given that, under this particular equilibrium, men receive right-swipes with a 0.491 probability, compared to 0.988 for women, thus replicating the high swiping and low matching rates for men as well as the opposite scenario for women.

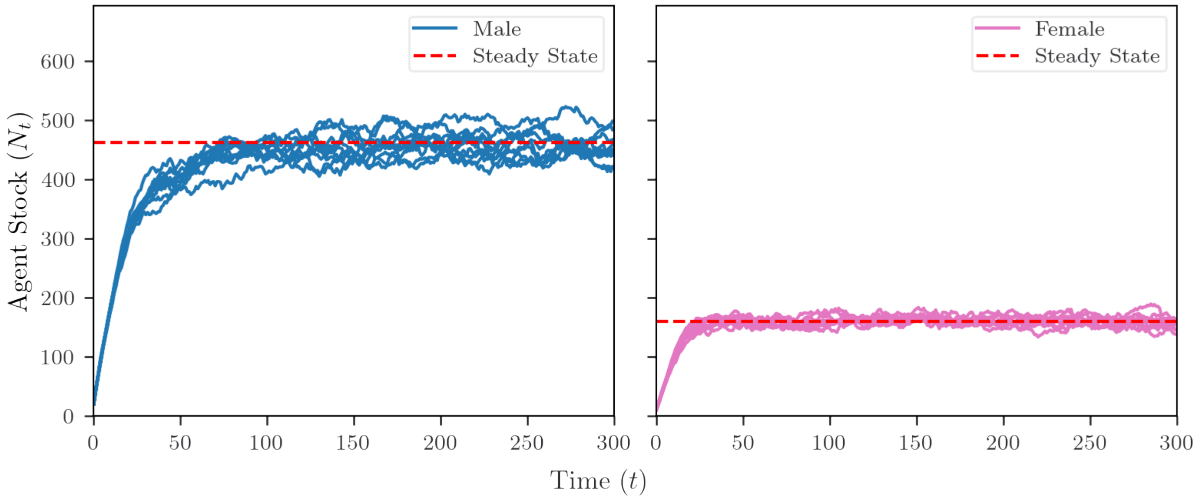
4 Agent-Based Simulations

4.1 Convergence and Dynamics

Given the lack of accessible SBDA user data, I developed on agent-based simulation environment to explore the evolution of both behavioural and market-level dynamics under the above theoretical foundations. Agent-based modelling (ABM) aims to explore "how macro phenomena emerges from micro level behaviour among a heterogeneous set of interacting agents" (Janssen, 2005). In essence, this methodology aims to study complex dynamical processes through computational simulations, as opposed to determining closed-form solutions for these through heavily simplified assumptions, which can sometimes result in large differences between predicted and real-life trajectories for complex systems (such as markets). When applied in combination with a micro-founded theoretical model, ABM can provide powerful insights by aiding in the identification of equilibrium states, which can be computationally expensive to approximate (and in some cases even non-existent).

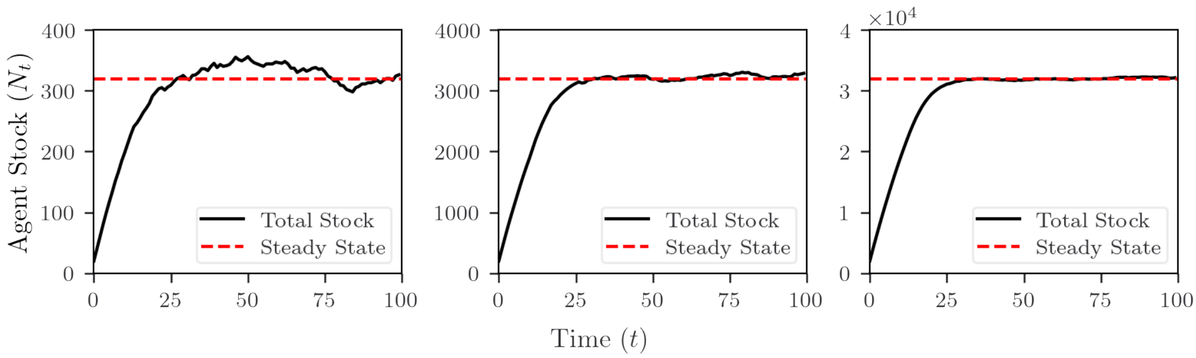
To start, I explored the convergence and stability of the SBDA market under various arbitrary exogenous configurations. In particular, Figure 6 shows the simulated evolution

Figure 6: Agent-Based Simulation Convergence



of both male and female agent masses over 300 time periods, with a 2:1 ratio between male and female arrival flows. As evident from these results, the computational procedures above are able to correctly predict the steady state market masses; furthermore, the ABM simulations show that the long side of the market (males) takes considerably longer to converge onto its steady-state level. One technical point worth noting is that, due to the limited capacity for computational simulations in handling non-discrete structures, the above simulations depict *agent stocks* as opposed to *agent masses*, as per our continuum model. Because of this, as well as the fact that agent departures and pairings follow random processes, the above equilibrium acts as a *stochastic steady state*, with convergence occurring in the stationary sense rather than in typical deterministic fashion. Nevertheless, we examine the limiting case of these dynamics, with Figure 7 depicting how, by the law of large numbers, stationary deviations around the steady state equilibrium level become negligible as the agent stocks tend to infinity, further confirming the stable nature of our equilibrium concept.

Figure 7: Agent-Based Simulation Convergence with Varying Sample Sizes



4.2 Social Efficiency

5 Conclusion

In this chapter we shall do a reference to an entry in the bibliography, `bibliography.bib`.

What we know of the invention of the flux capacitor is that Dr. Emmett Brown thought of this when hanging a clock in the bathroom. He was standing on his porcelain sink and slipped because it was wet, the resulting hit on the head was apparently a cause to this invention Olmeda (2021).

5.1 Future Work

The corresponding sketch made on this day has been attached in appendix A.

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A Proof for Proposition 1

Proof. To prove Proposition 1, we rely the following two equations; the first of which expresses the agent's value function in piecewise form, and the second of which describes the necessary condition for all reservation attractiveness values:

$$V(\theta, b) = \begin{cases} \overline{\mu} u(\theta) + \alpha\, \mathbb{E}_\theta \Big[V(\theta', b-1) \Big], & \theta > \widetilde{\omega}_b \\ \alpha\, \mathbb{E}_\theta \Big[V(\theta', b) \Big], & \theta \leq \widetilde{\omega}_b \end{cases} \tag{A.1}$$

$$\overline{\mu} u(\widetilde{\omega}_b) = \alpha\, \mathbb{E}_\theta \Big[\, V(\theta', b) - V(\theta', b-1) \, \Big] \tag{A.2}$$

To simplify notation, denote the continuation value at budget b by:

$$K_b := \alpha\, \mathbb{E}_\theta \left[V(\theta', b) \right]$$

Starting out with Equation A.2 and expanding out the expectation operator, we can use A.1 to substitute in the piecewise definitions of $V(\theta, b)$ over the appropriate intervals:

$$\begin{aligned} \overline{\mu} u(\widetilde{\omega}_b) &= \alpha \int_0^1 V(\theta', b) - V(\theta', b-1)\, dF_m(\theta') \\ &= \alpha \int_0^{\widetilde{\omega}_b} K_b\, dF_m(\theta') \; + \; \alpha \int_{\widetilde{\omega}_b}^1 \overline{\mu} u(\theta') + K_{b-1}\, dF_m(\theta') \\ &\quad - \; \alpha \int_0^{\widetilde{\omega}_{b-1}} K_{b-1}\, dF_m(\theta') \; - \; \alpha \int_{\widetilde{\omega}_{b-1}}^1 \overline{\mu} u(\theta') + K_{b-2}\, dF_m(\theta') \end{aligned} \tag{A.3}$$

Furthermore, Equation A.2 implies that:

$$\overline{\mu} u(\widetilde{\omega}_b) + K_{b-1} = K_b$$

$$\overline{\mu} u(\widetilde{\omega}_{b-1}) + K_{b-2} = K_{b-1}$$

Then, by substituting these expressions into A.3, we arrive at A.4:

$$\begin{aligned} \overline{\mu} u(\widetilde{\omega}_b) = \alpha \int_0^{\widetilde{\omega}_b} \overline{\mu} u(\widetilde{\omega}_b) + K_{b-1}\, dF_m(\theta') \; + \; \alpha \int_{\widetilde{\omega}_b}^1 \overline{\mu} u(\theta') + K_{b-1}\, dF_m(\theta') \\ - \; \alpha \int_0^{\widetilde{\omega}_{b-1}} K_{b-1}\, dF_m(\theta') \; - \; \alpha \int_{\widetilde{\omega}_{b-1}}^1 \overline{\mu} u(\theta') + K_{b-1} - \overline{\mu} u(\widetilde{\omega}_{b-1})\, dF_m(\theta') \end{aligned} \tag{A.4}$$

With some algebra, this simplifies down to the recurrence relation in Equation 2.7:

$$u(\widetilde{\omega}_b) = \alpha u(\widetilde{\omega}_b) F_m(\widetilde{\omega}_b) \; + \; \alpha u(\widetilde{\omega}_{b-1}) \Big[1 - F_m(\widetilde{\omega}_{b-1}) \Big] \; + \; \alpha \int_{\widetilde{\omega}_b}^{\widetilde{\omega}_{b-1}} u(\theta')\, dF_m(\theta') \tag{A.5}$$

Furthermore, to obtain the initial condition for the above, note that the right-swiping budget constraint imposes $V(\theta, 0) = 0, \forall b \in \mathcal{B}_w$. Then, A.1 and A.2 simplify to:

$$V(\theta, 1) = \begin{cases} \overline{\mu} u(\theta), & \theta > \widetilde{\omega}_1 \\ \alpha \, \mathbb{E}_\theta \Big[V(\theta', 1) \Big], & \theta \leq \widetilde{\omega}_1 \end{cases} \tag{A.6}$$

$$\overline{\mu} u(\widetilde{\omega}_1) = \alpha \, \mathbb{E}_\theta \Big[\, V(\theta', 1) \, \Big] \tag{A.7}$$

Beginning with A.7, we simplify until arriving at Equation 2.8:

$$\begin{aligned} \overline{\mu} u(\widetilde{\omega}_1) &= \alpha \, \mathbb{E}_\theta \Big[\, V(\theta', 1) \, \Big] \\ &= \alpha \int_0^{\widetilde{\omega}_1} K_1 \, dF_m(\theta') + \alpha \int_{\widetilde{\omega}_1}^1 \overline{\mu} u(\theta') \, dF_m(\theta') \\ &= \alpha \int_0^{\widetilde{\omega}_1} \overline{\mu} u(\widetilde{\omega}_1) \, dF_m(\theta') + \alpha \int_{\widetilde{\omega}_1}^1 \overline{\mu} u(\theta') \, dF_m(\theta') \\ &= \alpha \overline{\mu} u(\widetilde{\omega}_1) F_m(\widetilde{\omega}_1) + \alpha \int_{\widetilde{\omega}_1}^1 \overline{\mu} u(\theta') \, dF_m(\theta') \\ \implies u(\widetilde{\omega}_1) &= \alpha u(\widetilde{\omega}_1) F_m(\widetilde{\omega}_1) + \alpha \int_{\widetilde{\omega}_1}^1 u(\theta') \, dF_m(\theta') \end{aligned}$$

To conclude the proof, note that the existence and uniqueness of some $\widetilde{\omega}_b$ that satisfies A.2 is guaranteed given the assumptions on $u(\theta)$ being continuous and strictly increasing. Since the difference between any two consecutive continuation values must lie strictly between 0 and $u(1)$, then, by the Intermediate Value Theorem, there exists one and only one root $\widetilde{\omega}_b$ satisfying A.2 and, by extension the above reoccurrence relation. □